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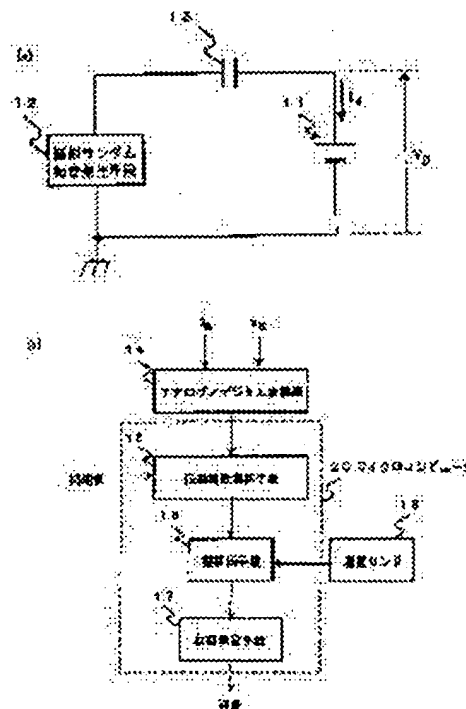
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## (54) METHOD AND APPARATUS FOR ANALYZING STATE OF BATTERY

(57)Abstract:

PROBLEM TO BE SOLVED: To provide a method and apparatus for analyzing the state of a battery for accurately analyzing the state such as a residual capacity of the battery by a low cost.

SOLUTION: An AC voltage  $v_B$  and AC current  $i_B$  of a battery 11 are sampled by an analog-digital converter 14 in the state that an AC signal output from a pseudo random noise generating means 12 is applied to the battery 11 to be analyzed via an impedance element 13. A transfer function of a discrete system having the battery 11 and the element 13 is estimated and calculated by a transfer function calculating means 15 from the obtained data, and a polarity of the function of an AC equivalent circuit of the battery 11 is calculated from the function of the system by a polarity calculating means 16. A state deciding means 17



decides the state of the battery 11 by using correlation to the polarity of the function of the equivalent circuit. Since the function of the system is used, an analog signal processing is not required, and the respective means can be realized, for example, by a microcomputer 20.

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 [Title of the Invention] The condition analysis approach and its equipment of a cell  
 [Claim(s)]  
 [Claim 1] The condition analysis approach of the cell which carries out the presumed operation of the transfer function of the discrete time system of the system which contains said cell from the time series data of the alternating current which flows on the alternating voltage which is the condition analysis approach of the cell in which a cell carries out condition analysis, and is built over said cell, and said cell, and is characterized by analyzing the condition of said cell using the transfer function of this discrete time system.  
 [Claim 2] The condition which is the condition analysis approach of a cell characterized by providing the following of analyzing a cell condition, impressed the AC signal to the cell for analysis, and impressed the AC signal to said cell The 1st process which samples the alternating current which flows on the alternating voltage concerning said cell, and said cell Said cell  
 [Claim 3] In the condition analysis approach of a cell according to claim 2, from the transfer function of

the discrete time system searched for by the presumed operation in said 2nd process After asking for the pole in the transfer function of this discrete time system, it has the 3rd process which changes into the pole in the transfer function of the continuous system of the alternating current equal circuit of said cell the pole for which it asked. The condition analysis approach of the cell characterized by analyzing the condition of said cell using the pole in the transfer function of the continuous system of the alternating current equal circuit of said cell for which it asked in said 3rd process.

[Claim 4] The condition analysis equipment of the cell characterized by to analyze the condition of said cell based on the transfer function of the discrete time system which was equipped with the means which carries out the presumed operation of the transfer function of the discrete time system of the system which contains said cell from the time series data of the alternating current which flows on the alternating voltage which is condition analysis equipment of the cell which analyzes a cell condition, and is built over said cell, and said cell, and carried out a presumed operation with this means.

[Claim 5] Condition analysis equipment of the cell which analyzes a cell condition characterized by providing the following An AC signal impression means to impress an AC signal to the cell for analysis <sup>! said</sup> A sampling means to sample the alternating current which flows on the alternating voltage concerning <sup>means</sup> said cell, and said cell when an AC signal is impressed to said cell by said AC signal impression means The transfer function operation means which carries out the presumed operation of the transfer function of the discrete time system of the system containing said cell from the time series data of the alternating voltage sampled by said sampling means, and alternating current

[Claim 6] While asking for the pole in the transfer function of this discrete time system from the transfer function of the discrete time system of the system which contains said cell called for by said transfer function operation means in the condition analysis equipment of a cell according to claim 5 Condition analysis equipment of the cell characterized by analyzing the condition of said cell based on the pole in the transfer function of said continuous system which was equipped with a pole calculation means to change into the pole in the transfer function of the continuous system of the alternating current equal circuit of said cell the pole for which it asked, and was searched for with said pole calculation means.

[Claim 7] Condition analysis equipment of a cell according to claim 6 characterized by providing the following Said pole calculation means is a factorization operation means to factorize the polynomial of the denominator of the transfer function of the discrete time system of the system containing said cell, and to calculate the complex solution of the pole in the transfer function of said discrete time system. A pole operation means to omit imaginary part from the complex solution of the pole for which it asked with said factorization operation means, and to pinpoint the pole in the transfer function of said discrete time system corresponding to the positive electrode and negative electrode of said cell from the remaining real part A pole conversion operation means to change into the pole in the transfer function of the continuous system of the alternating current equal circuit of said cell the pole in the transfer function of said discrete time system corresponding to the positive electrode and negative electrode of said cell which were specified with said pole operation means based on the sampling period by said sampling means

[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention relates to the condition analysis approach of the cell for analyzing and detecting conditions, such as a residue of the cell carried in pocket devices, such as an electric vehicle, a personal computer, or a cellular phone, and its equipment.

[0002]

[Description of the Prior Art] As a conventional method of analyzing conditions, such as a residue of a cell, there is an approach by the capacity test which measures [ 1st ] the electrical potential difference and current of a cell, and the alternating current impedance of a cell is measured [ 2nd ], and there is a method of judging the condition of a cell from correlation with the alternating current impedance and conditions, such as a residue of a cell, which were searched for beforehand.

[0003]

[Problem(s) to be Solved by the Invention] However, according to the 1st approach, while the detection

precision of the condition of a cell is good, since it is an analog signal processing circuit necessary, in requiring measurement of long duration, and instrumentating as condition analysis equipment of a cell for current potential measurement of a cell, there is a problem that cost starts.

[0004] Moreover, according to the 2nd approach, there is the advantage in which measurement can carry out in a short time compared with the 1st approach, i.e., a capacity test method, but in order to measure the amplitude and a phase using an analog signal, there is a problem of if an analog signal processing circuit is needed like the 1st approach, and cost starts in instrumentating, and the problem of being weak is also in a noise.

[0005] Since it is our prospective aim building the condition analysis equipment of a cell into the device by which a cell like pocket devices, such as an electric vehicle, a personal computer, or a cellular phone, is carried, and enabling it to detect the condition of the cell carried on real time, low cost and condition analysis equipment of a highly precise cell are desired.

[0006] In view of the above problems, this invention makes it a technical problem to offer the condition analysis approach of the cell which can analyze conditions, such as a residue of a cell, with low cost and a sufficient precision using digital signal processing, and the equipment using the approach.

[0007]

[Means for Solving the Problem] In order to solve the aforementioned technical problem, after asking for the transfer function of the discrete time system of the system which contains a cell first paying attention to there being correlation between transitions of a pole and the residues of a cell in the transfer function of the alternating current equal circuit of a cell by the presumed operation, this invention asks for the pole in the transfer function of the alternating current equal circuit of a cell from this transfer function, and, thereby, detects the condition of a cell. Since digital signal processing can perform the presumed operation of the transfer function of a discrete time system, in this invention, analog signal processing becomes unnecessary.

[0008] The solution means which invention of claim 1 provided carries out the presumed operation of the transfer function of the discrete time system of the system which contains said cell from the time series data of the alternating current which flows on the alternating voltage concerning said cell, and said cell as the condition analysis approach of a cell of analyzing conditions, such as a residue of a cell, and analyzes the condition of said cell using the transfer function of this discrete time system.

[0009] In order to carry out the presumed operation of the transfer function of the discrete time system of the system containing a cell from the time series data of the alternating current which flows on the alternating voltage and the cell concerning a cell according to invention of claim 1, analog signal processing is unnecessary, and since digital signal processing can perform all, while LSI-ization by the one chip microcomputer, DSP, etc. is attained and the cost at the time of instrumentating becomes low, it becomes strong by the noise. Moreover, from the transfer function of a discrete time system, it can ask for the pole in the transfer function of the alternating current equal circuit of a cell, and the condition of a cell can be analyzed using the correlation between the pole in the transfer function of the alternating current equal circuit of a cell, and the condition of a cell.

✕ [0010] Moreover, invention of claim 2 materializes invention of claim 1 further, and sets it as the condition analysis approach of a cell of analyzing conditions, such as a residue of a cell, in the condition of having impressed the AC signal to the cell for analysis, and having impressed the AC signal to said cell. The 1st process which samples the alternating current which flows on the alternating voltage concerning said cell, and said cell, It has the 2nd process which carries out a presumed operation, using the alternating voltage and alternating current which sampled the transfer function of the discrete time system of the system containing said cell at said 1st process as time series data. The condition of said cell is analyzed using the transfer function of the discrete time system searched for by the presumed operation in said 2nd process.

[0011] Moreover, in invention of claim 3, it sets to the condition analysis approach of the cell of said claim 2. After asking for the pole in the transfer function of this discrete time system from the transfer function of the discrete time system searched for in said 2nd process, It shall have the 3rd process which changes into the pole in the transfer function of the continuous system of the alternating current equal

circuit of said cell the pole for which it asked, and the condition of said cell shall be analyzed using the pole in the transfer function of the continuous system of the alternating current equal circuit of said cell for which it asked in said 3rd process.

[0012] Moreover, the solution means which invention of claim 4 provided is equipped with the means which carries out the presumed operation of the transfer function of the discrete time system of the system which contains said cell from the time series data of the alternating current which flows on the alternating voltage concerning said cell, and said cell as condition analysis equipment of the cell which analyzes conditions, such as a residue of a cell, and analyzes the condition of said cell based on the transfer function of the discrete time system which carried out a presumed operation with this means.

[0013] According to invention of claim 5, to the presumed operation of the transfer function of a discrete time system, analog signal processing is unnecessary, and the means which carries out the presumed operation of the transfer function of the discrete time system of the system containing a cell from the time series data of the alternating current which flows on the alternating voltage and the cell concerning a cell since digital signal processing can perform all becomes strong by the noise while the cost at the time of becoming realizable and instrumentating by the one chip microcomputer, DSP, etc. becomes low. Moreover, from the transfer function of the discrete time system searched for with said means, it can ask for the pole in the transfer function of the alternating current equal circuit of a cell, and the condition of a cell can be analyzed using the correlation between the pole in the transfer function of the alternating current equal circuit of a cell, and the condition of a cell.

X [0014] moreover, as condition analysis equipment of the cell which invention of claim 5 materializes invention of claim 4, and analyzes conditions, such as a residue of a cell When an AC signal is impressed to said cell by AC signal impression means to impress an AC signal to the cell for analysis, and said AC signal impression means, A sampling means to sample the alternating current which flows on the alternating voltage concerning said cell, and said cell, It has the transfer function operation means which carries out the presumed operation of the transfer function of the discrete time system of the system containing said cell from the time series data of the alternating voltage sampled by said sampling means, and alternating current. <sup>mean</sup>

[0015] And while asking for the pole in the transfer function of this discrete time system from the transfer function of the discrete time system of the system which contains said cell called for by said transfer function operation means in the condition analysis equipment of the cell of said claim 5 in invention of claim 6 It shall have a pole calculation means to change into the pole in the transfer function of the continuous system of the alternating current equal circuit of said cell the pole for which it asked, and the condition of said cell shall be analyzed based on the pole in the transfer function of said continuous system searched for with said pole calculation means.

[0016] In invention of claim 7, furthermore, the pole calculation means in the condition analysis equipment of the cell of said claim 22 The polynomial of the denominator of the transfer function of the discrete time system of the system containing said cell is factorized. A factorization operation means to calculate the complex solution of the pole in the transfer function of said discrete time system, A pole operation means to omit imaginary part from the complex solution of the pole for which it asked with said factorization operation means, and to pinpoint the pole in the transfer function of said discrete time system corresponding to the positive electrode and negative electrode of said cell from the remaining real part, The pole in the transfer function of said discrete time system corresponding to the positive electrode and negative electrode of said cell which were specified with said pole operation means Based on the sampling period by said sampling means, it shall have a pole conversion operation means to change into the pole in the transfer function of the continuous system of the alternating current equal circuit of said cell.

[0017]

[Embodiment of the Invention] First, the fundamental principle of this invention is explained.

[0018] (1) The definition of a cell transfer function

In the alternating current impedance measurement of a cell, if the electrode of a cell and the interface of the electrolytic solution are polarized with the minute AC signal of amplitude extent of 10mV or less

superimposed on direct current voltage, it can be considered that the AC signal which hardly disturbs an interface and is acquired is change near the direct-current potential.

[0019] The alternating current equal circuit of the cell when giving a minute AC signal becomes like drawing 1. The parallel connection of the capacity of an electric duplex layer and the faraday impedance which are generated between an electrode interface and an electrolytic-solution interface can express the impedance by contact to an electrode and the electrolytic solution. A faraday impedance is expressed with the series connection of the polarization resistance (charge transfer resistance) of an electrode, and the capacity component of an electrode when it assumes that the electrode reaction of a charge transfer process is rate-limiting here. An electric duplex layer capacity [ in / n / 31p and / 31 / on drawing 1 and / in the polarization resistance of a positive electrode and a negative electrode, and 32p / a positive electrode ], 32n an electric duplex layer capacity in a negative electrode, and 33p and 33n The capacity component of a positive electrode and a negative electrode, 34 is resistance of the electrolytic solution and the impedance of a positive electrode is expressed by the parallel connection of the faraday impedance which consists of polarization resistance 31p and capacity component 33p, and electric duplex layer capacity 32p. The impedance of a negative electrode is expressed by with a capacity [ the faraday impedance and an electric duplex layer capacity of 32n ] which consist of 31n of polarization resistance, and 33n of capacity components parallel connection.

[0020] Here, it is  $R_n$  about  $R_p$  and the resistance of 31n of polarization resistance in the resistance of polarization resistance 31p. If it carries out,

[0021]

[Equation 1]

$$\text{正極} : R_p = \frac{RT}{nF i_{op}} \quad \dots (1)$$

$$\text{負極} : R_n = \frac{RT}{nF i_{on}} \quad \dots (2)$$

[0022] It is expressed. a formula (1) and (2) -- setting --  $R$  -- in a Boltzmann's constant and  $T$ , a Faraday constant and  $i_{op}$  show the exchange current of a positive electrode, and, as for absolute temperature and  $n$ ,  $i_{on}$  shows the exchange current of a negative electrode, as for the charge number of electrode reaction, and  $F$ . Moreover, in drawing 1, the capacity value of electric duplex layer capacity 32p [ in / in  $C_{dp}$  / a positive electrode ], capacity value with an electric duplex layer capacity [ in / in  $C_{dn}$  / a negative electrode ] of 32n, and  $R_{el}$  are the resistance of the resistance 34 of the electrolytic solution.

[0023] The frequency of an AC signal is comparatively high, and when the effect which the capacity components 33p and 33n of an electrode have on the impedance of a cell can be disregarded, the alternating current equal circuit of a cell can delete the capacity components 33p and 33n from drawing 1, and can regard them like drawing 2.

[0024] the cell in alternating current polarization -- the time -- an eternal linear system -- assuming -- if - - drawing 2 -- being shown -- an alternating current -- an equal circuit -- it can set -- a cell -- a transfer function --  $H_B$  -- ( --  $s$  -- )

[0025]

[Equation 2]

$$H_B(s) = \frac{1}{sR_p C_{dp} + 1} + R_{e1} + \frac{1}{sR_n C_{dn} + 1} \dots (3)$$

[0026] It becomes. Moreover, if the impedance of the impedance component used for the alternating current impedance measurement of a cell is set to  $H_I(s)$ , all transfer function  $G(s)$  of the system which consists of a cell and an impedance component will be defined as follows.

[0027]

[Equation 3]

$$G(s) = \frac{V_B}{I_B} = H_I(s) + H_B(s) = \frac{1}{sR_p C_{dp} + 1} + R_{e1} + \frac{1}{sR_n C_{dn} + 1} \dots (4)$$

[0028] Here, it is  $v_B$ . The electrical potential difference and  $i_B$  which are impressed to a cell at the time of alternating current impedance measurement. It is the current which flows a cell at the time of alternating current impedance measurement. The degree of the pole of all transfer function  $G(s)$  serves as the sum of the degree of the pole in the impedance  $H_I$  of an impedance component (s), and the degree of the pole in the cell transfer function  $H_B(s)$ .

[0029] Drawing 3 is a complex impedance plot of a cell which has the cell transfer function  $H_B(s)$  as shown in a formula (3). As shown in drawing 3, the complex impedance of a cell becomes the resistance  $R_{e1}$  of the electrolytic-solution resistance 34 with the increment in the angular frequency  $\omega$  of an AC signal through the semicircle locus by the negative electrode, and the semicircle locus by the positive electrode at the time of  $\omega = \infty$ . If angular frequency in the 1st pole  $s_1$  and the 2nd pole  $s_2$  is set to  $\omega_{e1}$  and  $\omega_{e2}$ , respectively,

$$\omega_{e1} = -1/R_n C_{dn} \text{ [rad/s]} \dots (5)$$

$$\omega_{e2} = -1/R_p C_{dp} \text{ [rad/s]} \dots (6)$$

It is come out and given.

[0030] (2) The presumed operation of a transfer function

this invention -- a cell -- the time -- an eternal linear system -- it is -- \*\* -- assuming -- a formula -- (-- all transfer function  $G(s)$  expressed with 4) is given as a general transfer function in the discrete time system of the following forms.

[0031]

[Equation 4]

$$G(z, \theta) = \frac{b_1 z^{-1} + \dots + b_n z^{-n}}{1 + a_1 z^{-1} + \dots + a_n z^{-n}} = \frac{B(z)}{A(z)} \dots (7)$$

[0032] A transfer function  $G(z, \theta)$  is presumed by determining the multiplier of a formula (7) based on the I/O signal of a cell. Generally, the approach of presuming the transfer function of a system based on a I/O data is called system identification. Drawing 4 is drawing showing the model used for system identification, and is the transfer function  $H_n(z, \theta)$  of a noise,

$$H_n(z, \theta) = 1/A(z) \dots (8)$$

It comes out, and when expressed, this model turns into an autoregression (ARX) model with an external input. It is an output response supposing output signal  $y(t)$  is given by primary association of input signal  $u(t)$  and noise signal  $e(t)$ , as shown in drawing 4,

$$A(z) y(t) B[=](z) u(t) + e(t) \dots (9)$$

It becomes.

[0033] Recursion vector  $\phi$  by the multiplier parameter  $\theta$  and I/O data sequence of the transfer

function  $G(z, \theta)$  to presume  $(t)$ ,  
 [0034]  
 [Equation 5]

$$\theta = (a_1 \cdots a_n b_1 \cdots b_n)^T \cdots (10)$$

$$\varphi(t) = [-y(t-1) \cdots -y(t-n) u(t-1) \cdots u(t-m)]^T \cdots (11)$$

[0035] When it carries out, a formula (9) is,  
 $y(t) = \varphi^T(t) \theta + e(t)$  -- (12)

When it is expressed and the matrix operation of a formula (12) is solved for example, by the RLS serial method, multiplier parameter  $\theta(t)$  is,

[0036]  
 [Equation 6]

$$\theta(t) = \theta(t-1) + K(t) e(t)$$

$$e(t) = y(t) - \varphi^T(t) \theta(t-1)$$

$$K(t) = \frac{p(t-1) \varphi(t)}{1 + \varphi^T(t) p(t-1) \varphi(t)}$$

$$p(t) = \frac{p(t-1) - p(t-1) \varphi(t) \varphi^T(t) p(t-1)}{1 + \varphi^T(t) p(t-1) \varphi(t)} \cdots (13)$$

[0037] It is come out and given. This multiplier parameter  $\theta(t)$  is converged after the repeat operation of the count of predetermined.

[0038] In addition, generally the initial value of an operation is,  
 $\theta(0) = 0, P(0) = \alpha Id$  -- (14)

\*\* -- although carried out -- for example

$$R_p = 0.001 \sim 10 \quad [\Omega]$$

$$R_n = 0.001 \sim 10 \quad [\Omega]$$

$$C_{dp} = 10^{-6} \sim 10^{-2} \quad [F]$$

$$C_{dn} = 10^{-6} \sim 10^{-2} \quad [F] \cdots (15)$$

If the initial value of \*\*\*\*\* is used, the repeat operation to convergence can be reduced.

[0039] (3) Calculation of the pole of a discrete time system

The case where the number of the poles of a discrete time system and a continuous system is made in agreement is explained.

[0040] (3-1) When an impedance component is pure resistance

Since the degree of the pole in all transfer function  $G(s)$  shown in a formula (4) becomes the 2nd order when an impedance component is pure resistance, system identification is performed noting that the degree of the pole in the transfer function  $G(z, \theta)$  of the discrete time system shown in a formula (7) is also the 2nd order. Namely, a formula (7),

[0041]

[Equation 7]

$$G(z, \theta) = \frac{b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}} \quad \dots (16)$$

[0042] It becomes. It is a pole in the transfer function  $G(z, \theta)$  of the discrete time system shown in a formula (16) when each parameter  $\theta$  shall be converged in a formula (16) here,

[0043]

[Equation 8]

$$z^2 + \left(\frac{a_1}{b_2} + \frac{1}{b_1}\right) z + \left(\frac{a_2}{b_2} + \frac{a_1}{b_1}\right) = 0 \quad \dots (17)$$

[0044] It is alike and is given with the solution of the quadratic equation of  $z$  as shown. It is the multiplier of a formula (17) here,

[0045]

[Equation 9]

$$\begin{aligned} \left(\frac{a_1}{b_2} + \frac{1}{b_1}\right) &= A_1 \\ \left(\frac{a_2}{b_2} + \frac{a_1}{b_1}\right) &= A_2 \quad \dots (18) \end{aligned}$$

[0046] If it sets, two poles can be found in a formula of a solution.

[0047]

[Equation 10]

$$z_1, z_2 = \frac{-A_1 \pm \sqrt{A_1^2 - 4A_2}}{2} \quad \dots (19)$$

[0048] Generally this solution is given with the following complex solutions.

[0049]

$$z_1 = \sigma_1 + j \beta_1$$

$$z_2 = \sigma_2 + j \beta_2 \quad \dots (20)$$

Furthermore, since two poles in all transfer function  $G(s)$  of a continuous system to search for originally existed on the real axis on  $s$  flat surface, the imaginary component of a formula (20) was omitted from the basis that there are two poles on the real axis of  $z$  flat surface also in the transfer function  $G$  of a discrete time system  $(z, \theta)$ ,

$$z_1 = \sigma_1$$

$$z_2 = \sigma_2 \quad \dots \quad (21)$$

It considers as the pole of the cell transfer function  $G$  in a discrete time system  $(z, \theta)$ .

[0050]  $|z_2| < |z_1| \rightarrow (22)$

It is alike, it follows and the size comparison of the absolute value with poles  $z_1$  and  $z_2$  is carried out, when a formula (22) is truth, the pole corresponding to the negative electrode of a cell in a pole  $z_1$  and a pole  $z_2$  turn into a pole corresponding to the positive electrode of a cell, and when a formula (22) is a false, the pole corresponding to the positive electrode of a cell in a pole  $z_1$  and a pole  $z_2$  turn into a pole corresponding to the negative electrode of a cell.

[0051] (3-2) When an impedance component contains pure capacity

When an impedance component contains pure capacity, system identification is performed noting that the degree of the pole in the transfer function  $G(z, \theta)$  of the discrete time system shown in a formula (7) is also the 3rd order, since the degree of the thing pole in all transfer function  $G(s)$  shown in a formula (4) becomes the 3rd order. Namely, a formula (7),

[0052]

[Equation 11]

$$G(z, \theta) = \frac{b_1 z^{-1} + b_2 z^{-2} + b_3 z^{-3}}{1 + a_1 z^{-1} + a_2 z^{-2} + a_3 z^{-3}} \quad \dots \quad (23)$$

[0053] It becomes. The pole of the transfer function  $G(z, \theta)$  shown in a formula (23),

[0054]

[Equation 12]

$$z^3 + b_3 \left( \frac{a_1}{b_3} + \frac{1}{b_2} \right) z^2 + b_3 \left( \frac{1}{b_1} + \frac{a_1}{b_2} + \frac{a_2}{b_3} \right) z$$

$$+ b_3 \left( \frac{a_1}{b_1} + \frac{a_2}{b_2} + \frac{a_3}{b_3} \right) = 0 \quad \dots \quad (24)$$

[0055] It is alike and is given with the solution of the cubic equation of  $z$  as shown. And three poles  $z_1$ ,  $z_2$ , and  $z_3$ ,

[0056]

[Equation 13]

$$z_1 = y_1 - \frac{r}{3}, \quad z_2 = y_2 - \frac{r}{3}, \quad z_3 = y_3 - \frac{r}{3}$$

$$y_1 = u_1 + v_1, \quad y_2, y_3 = -\frac{u_1 + v_1}{2} \pm \frac{u_1 - v_1}{2} \sqrt{3} i$$

[0057] Generally this solution is given with the following complex solutions.

[0058]

$$z_0 = \sigma_0 + j \beta_0$$

$$z_1 = \sigma_1 + j \beta_1$$

$$z_2 = \sigma_2 + j \beta_2 \quad \dots (26)$$

Furthermore, since three poles of all transfer function  $G(s)$  of a continuous system to search for originally exist on the real axis on  $s$  flat surface, the imaginary component of a formula (26) is omitted from a basis that a pole is on the real axis of  $z$  flat surface also in the transfer function  $G$  of a discrete time system ( $z, \theta$ ).  $z_0, z_1$ , and  $z_2$  to descending of the absolute value,

$$z_0 = \sigma_0$$

$$z_1 = \sigma_1$$

$$z_2 = \sigma_2 \quad \dots (27)$$

It can be found by carrying out. Among these, it removes as a pole of an impedance component which should be set to  $z=1$ , and the largest pole  $z_0$  of an absolute value is about the remaining poles  $z_1$  and  $z_2$ ,

$$|z_2| < |z_1| \quad \dots (28)$$

It is alike, and it follows and the size comparison of the absolute value is carried out. When a formula (28) is truth, the pole corresponding to the negative electrode of a cell in a pole  $z_1$  and a pole  $z_2$  turn into a pole corresponding to the positive electrode of a cell, and when a formula (28) is a false, the pole corresponding to the positive electrode of a cell in a pole  $z_1$  and a pole  $z_2$  turn into a pole corresponding to the negative electrode of a cell.

[0059] (4) Conversion of the pole from a discrete time system to a continuous system

Drawing 5 is drawing which expresses  $s$  flat-surface onto mapping from  $z$  flat surface. The poles  $s_1$  and  $s_2$  in a continuous system as shown in a formula (5) and (6) from the poles  $z_1$  and  $z_2$  in a discrete time system by map as shown in drawing 5 are called for. If the sampling time in a discrete time system is set to  $T$  [s], it is the map of the pole from  $z$  flat surface to  $s$  flat surface,

[0060]

[Equation 14]

$$U_1 = \sqrt[3]{-\frac{q}{2} + \sqrt{\frac{q^2}{4} + \frac{p^3}{27}}}, \quad V_1 = \sqrt[3]{-\frac{q}{2} + \sqrt{\frac{q^2}{4} + \frac{p^3}{27}}}$$

$$p = s - \frac{r^2}{3}, \quad q = \frac{2r^3}{27} - \frac{rs}{3} + t$$

$$r = A_1, \quad s = A_2, \quad t = A_3$$

$$A_1 = b_3 \left( \frac{a_1}{b_3} + \frac{1}{b_2} \right)$$

$$A_2 = b_3 \left( \frac{1}{b_1} + \frac{a_1}{b_2} + \frac{a_2}{b_3} \right)$$

$$A_3 = b_3 \left( \frac{a_1}{b_1} + \frac{a_2}{b_2} + \frac{a_3}{b_3} \right) \dots (25)$$

$$s = \frac{1}{T} \ln z \dots (29)$$

[0061] It is alike and is carried out by following.

[0062] (5) The condition of a cell, and correlation of transition of a pole

A residue can estimate the condition of a cell. A residue means the remaining things of quantity of electricity charged by the cell. Correlation is between transition of the pole in a cell transfer function, and the residue of a cell.

[0063] Drawing 6 is drawing showing the complex impedance plot of a lithium ion battery, and is drawing showing change of the complex impedance plot accompanying change of the residue of a cell. (a), (b), (c), and (d) are the cases where residues are 100%, 50%, 10%, and 0%, among this drawing, respectively. the polarization resistance  $31p$  and  $31n$  shown in drawing 2 -- each resistance  $R_p$  and  $R_n$  It changes according to change of the exchange current density  $i_{op}$  and ion resulting from the chemical reaction of the positive electrode accompanying the charge and discharge of a cell, and a negative electrode. For this reason, it follows on change of the residue of a cell and they are the polarization resistance [  $31p$  and  $31n$  ] resistance  $R_p$  and  $R_n$ . Since it changes, as shown in drawing 6, a complex impedance plot also changes with change of the residue of a cell. Therefore, the angular frequency of a pole also changes with change of the residue of a cell.

[0064] Drawing 7 is a graph which shows the residue of a cell, and correlation with the angular frequency  $\omega$  of the pole in a cell transfer function, and (a) and (b) are the things of the 1st pole and the 2nd pole among this drawing, respectively. The residue of a cell decreases, so that there are so many

residues of a cell that the angular frequency  $\omega$  of a pole is high and the angular frequency  $\omega$  of a pole is low, as shown in drawing 7.

[0065] (Gestalt of operation) It explains hereafter, referring to a drawing about 1 operation gestalt of this invention.

[0066] Drawing 8 is drawing showing the configuration of the condition analysis equipment of the cell concerning the operation gestalt of this invention, and drawing showing the system to which (a) impresses an AC signal to a cell, and (b) are the block diagrams showing the configuration of the part which performs condition analysis of a cell among this drawing. The condition analysis equipment of the cell concerning this operation gestalt shown in drawing 8 carries out presumed evaluation of the condition of the cell 11 for analysis, for example, the degree of a residue. 14 is a pseudo-random noise generating means to output the AC signal which impresses 11 to the cell for analysis and impresses 12 to a cell 11 in drawing 8, the impedance component by which 13 was prepared between the cell 11 and the pseudo-random noise generating means 12, and the alternating voltage  $v_B$  concerning a cell 11. And alternating current  $i_B$  which flows on a cell 11 It is the analog-to-digital converter as a sampling means which is sampled and is changed into digital value from an analog value.

[0067] Moreover, the transfer function operation means which carries out the presumed operation of the transfer function showing the property of a system that 15 consists of a cell 11 and an impedance component 13 based on the output data of an analog / digital transducer 14 of a discrete time system, A pole calculation means to compute the pole in the transfer function of the continuous system of a cell 11 from the transfer function of the discrete time system by which the presumed operation of 16 was carried out with the transfer function operation means 15, It is a temperature sensor as a condition judging means to judge the condition of a cell based on the pole where 17 was computed by the pole calculation means 16, and a thermometry means for 18 to measure the ambient temperature of a cell 11 and to output to the pole calculation means 16. The transfer function operation means 15, the pole calculation means 16, and the condition judging means 17 are realized by the microcomputer 20 with this operation gestalt.

[0068] Drawing 9 is a flow chart which shows actuation of the condition analysis equipment of the cell concerning this operation gestalt shown in drawing 8. Actuation of the condition analysis equipment of the cell hereafter built over this operation gestalt shown in drawing 8 with reference to drawing 9 is explained.

[0069] In step S1, an AC signal is first impressed to the cell 11 used as the candidate for analysis. A frequency sweep may be carried out so that the frequency of the pole in the transfer function of a cell 11 may be included using a pseudo-random noise generating means by which a frequency is adjustable at this time, but with this operation gestalt, the pseudo-random noise generating means 12 shall output the AC signal of the frequency band which includes enough the frequency of the pole in the transfer function of a cell 11 so that it can analyze efficiently.

[0070] Drawing 10 is a graph which shows an example of the frequency characteristics of the pseudo-random noise generating means 12, an axis of abscissa is a frequency [Hz] and an axis of ordinate is the amplitude [dB]. As shown in drawing 10, the frequency band of the AC signal outputted from the pseudo-random noise generating means 12 needs to contain the component of the angular frequency  $\omega_1$  in the 1st pole S1 of the transfer function of a cell 11, and the angular frequency  $\omega_2$  in the 2nd pole S2. By using such a pseudo-random noise generating means 12, a frequency sweep becomes unnecessary. Moreover, the amplitude of the AC signal outputted from the pseudo-random noise generating means 12 is below extent that can disregard the effect of turbulence of an electrode interface, and is about 10mV or less.

[0071] What is necessary is just to constitute the pseudo-random noise generating means 12 using the noise source which generates a noise signal like white noise. Moreover, the false noise signal generation means using a pseudo-random sign like a noise source using an M sequence sign as shown in drawing 11 may be used. In drawing 11, the flip-flop as a delay operator with which 41 has a predetermined time delay, and 42 are EXCLUSIVE-OR-operation machines. In addition, although the hardware which used the flip-flop and the EXCLUSIVE-OR-operation machine has realized the false noise signal generation

means in drawing 11, there is also the approach of realizing using the software of making a pseudo-random sign pattern memorize and output to the memory of a microprocessor etc.

[0072] Moreover, with the condition analysis equipment of the cell concerning this operation gestalt which prevents forming direct-current pass between a cell 11 and the pseudo-random noise generating means 12 in case an AC signal is impressed to a cell 11, and shows it to drawing 8, an impedance component 13 has a large capacity enough, and the capacitor whose capacity value is known is used for it as an impedance component 13.

④ [0073] Next, alternating voltage  $v_B$  built over a cell 11 in step S2 And alternating current  $i_B$  which flows on a cell 11 It samples and asks for the time series I / O data used for the presumed operation of the transfer function of a discrete time system. Step S2 is performed by an analog / digital converter 14. Alternating voltage  $v_B$  concerning a cell 11 And alternating current  $i_B$  which flows on a cell 11 Recursion vector  $\phi(t)$  by the I / O data sequence as shown in a formula (11) is calculated from the digital value which was equivalent to input signal  $u(t)$  in the ARX model shown in drawing 4, and output-signal  $y(t)$ , respectively, therefore was sampled by the analog / digital transducer 14 with the predetermined time interval. Alternating voltage  $v_B$  which in other words is built over a cell 11 And alternating current  $i_B$  which flows on a cell 11 It becomes the time series I / O data used for the presumed operation of the transfer function of a discrete time system through the analog / digital transducer 14 as a sampling means.

[0074] Next, in step S3, the presumed operation of the transfer function of a discrete time system is carried out using the time series I / O data for which it asked at step S2. Step S3 is performed by the transfer function operation means 15 according to the procedure explained by the term of the presumed operation of (2) cell transfer function in the fundamental principle of this invention. That is, the transfer function operation means 15 is the alternating voltage  $v_B$  sampled by the analog / digital converter 14 and alternating current  $i_B$ . Time series I / O data  $u(t)$ , It asks for recursion vector [ of a formula (11) ]  $\psi(t)$  as  $y(t)$ , and a transfer function presumption operation as shown in a formula (13) using the initial value given by the formula (14) or (15) is performed, and it asks for multiplier parameter [ of a formula (10) ]  $\theta(t)$ , and asks for the transfer function of a discrete time system as shown in a formula (7).

[0075] Next, in step S4, the pole in the transfer function of a continuous system is computed from the transfer function of the discrete time system searched for at step S3. Step S4 is performed by the pole calculation means 16 according to the procedure explained by the term of conversion of calculation of the pole of (3) discrete time systems in the fundamental principle of this invention, and the pole from (4) discrete time systems to a continuous system.

[0076] Drawing 12 is the block diagram showing the configuration of the pole calculation means 16. First, factorization operation means 16a factorizes the rational polynomial which is the denominator of the transfer function of the discrete time system presumed by the transfer function operation means 15 at step S3. since pure capacity is given as an impedance component 13 with this operation gestalt -- the fundamental principle of this invention -- it can set (3-2) -- as explained, polynomial  $A(z)$  which is the denominator of a transfer function as shown in the presumed formula (7) is factorized according to a formula (25) from a formula (23), after omitting a term higher order than the 3rd order.

[0077] As shown in a formula (27), pole operation means 16b omits imaginary part from the complex solution acquired from a formula (25), considers only as real part, performs a size comparison according to a formula (28) further, and determines the pole corresponding to the positive electrode and negative electrode of a cell 11.

[0078] 16d of pole conversion operation means changes the pole to  $s$  field from  $z$  field using sampling period  $T$  according to a formula (29). Cell transfer function  $H_B$  of the continuous system given by factorization operation means 16a, pole operation means 16b, and pole conversion operation means 16c by the formula (3) from the transfer function of a discrete time system The pole in ( $s$ ) is called for.

[0079] The pole calculation means 16 in this operation gestalt is the cell transfer function  $H_B$  of a continuous system which is further equipped with 16d of pole temperature compensation means, and was called for by factorization operation means 16a, pole operation means 16b, and pole conversion operation means 16c. The ambient temperature of the cell measured by the temperature sensor 18 has

amended the pole in (s).

[0080] Temperature compensation of a pole is performed as follows. A temperature sensor 18 measures the skin temperature or ambient temperature of a cell 11. As shown in a formula (1) and (2), it is the resistance  $R_p$  of polarization resistance 31p of a positive electrode. And resistance  $R_n$  of 31n of polarization resistance of a negative electrode. Since it is proportional to both the absolute temperature  $T$ , the angular frequency of the pole shown by a formula (5) and (6) is in inverse proportion to absolute temperature. Here, it is assumed that the temperature of the cell 11 interior is equal to the temperature measured with the temperature sensor 18. It is  $T_a$  about reference temperature (experiment temperature which acquired correlation with a pole and the condition of a cell). It is  $T_d$  about the temperature measured with [K] and a temperature sensor 18. If [K], it is reference temperature  $T_a$ . The resistance  $R_p$  of the polarization resistance which can be set, and  $R_n$  Temperature  $T_d$ . The relation between resistance  $R_p'$  of the polarization resistance which can be set, and  $R_n'$  is from a formula (1) and (2),

[0081]

[Equation 15]

$$\text{正極： } R_p' = R_p \left(1 + \frac{T_d - T_a}{273}\right) \quad [\Omega] \quad \cdots (30)$$

$$\text{負極： } R_n' = R_n \left(1 + \frac{T_d - T_a}{273}\right) \quad [\Omega] \quad \cdots (31)$$

[0082] \*\* -- it becomes like. A formula (30) and (31) to reference temperature  $T_a$ . The angular frequency  $\omega_1$  and  $\omega_2$  of the pole which can be set is temperature  $T_d$ . Angular-frequency  $\omega_1'$  of a pole which can be set, and  $\omega_2'$  are amended like a degree type, and it asks.

[0083]

[Equation 16]

$$\text{正極： } \omega_1 = \omega_1' \left(1 + \frac{T_d - T_a}{273}\right) \quad [\text{rad/s}] \quad \cdots (32)$$

$$\text{負極： } \omega_2' = \omega_2' \left(1 + \frac{T_d - T_a}{273}\right) \quad [\text{rad/s}] \quad \cdots (33)$$

[0084] It becomes. 16d of pole temperature compensation means is the cell transfer function HB of the continuous system searched for by pole conversion operation means 16c. According to a formula (32) and (33), temperature compensation of the angular frequency of the pole in (s) is carried out, and it is outputted.

[0085] Finally in step S5, the residue of a cell is judged based on the angular frequency of the pole called for by step S4. Step S5 is performed by the condition judging means 17 according to the procedure explained by the term of correlation with the condition of (5) cells and transition of a pole in the fundamental principle of this invention.

[0086] In addition, when the pseudo-random noise generating means 12 has a direct-current-offset electrical potential difference equal to a cell 11, it is possible to omit an impedance component 13. Without minding an impedance component, drawing 13 is drawing showing the configuration of the condition analysis equipment of the cell which impresses an AC signal on a cell 11, and shows only the system which impresses an AC signal to a cell 11. In drawing 13, 12A is an electrical-potential-

difference offset pseudo-random noise generating means with a direct-current-offset electrical potential difference equal to a cell 11. The electrical-potential-difference offset noise source which generates a noise signal may constitute electrical-potential-difference offset pseudo-random noise generating means 12A like the pseudo-random noise generating means 12 shown in drawing 8.

[0087] Alternating voltage  $v_B$  concerning the cell 11 as well as the condition analysis equipment of the cell which also shows the condition analysis equipment of the cell of drawing 13 to drawing 8 And alternating current  $i_B$  which flows on a cell 11 The condition of a cell 11 can be judged by sampling and calculating the transfer function of a discrete time system. However, since in the case of the condition analysis equipment of the cell of drawing 13 it corresponds when the impedance component in the fundamental principle of this invention (3-1) is pure resistance Factorization operation means 16a which constitutes the pole calculation means 16 factorizes rational polynomial  $A(z)$  which is the denominator of the transfer function of the discrete time system presumed by the transfer function operation means 15 according to a formula (19) from a formula (17), after omitting a term higher order than the 2nd order. [0088] In addition, it is good also as a configuration which gives the initial value beforehand calculated based on the polarization resistance and the capacity component of an electrode of a cell 11 for analysis to the transfer function operation means 15. Thereby, the convergency of the presumed operation of the transfer function of a discrete time system can be raised.

[0089] In addition, in the pole calculation means 16, 16d of pole temperature compensation means may not be at an indispensable component. In this case, a temperature sensor 18 becomes unnecessary.

[0090] Moreover, the condition analysis equipment of the cell which judges the condition of cells other than a residue is also considered from the transfer function of the discrete time system searched for by the transfer function operation means 15. For example, it is possible from the transfer function of a discrete time system to judge the safety and degradation condition of a cell etc.

[0091] In addition, as an option, the degree of the pole of the transfer function of the discrete time system to presume is made into arbitration, and correlation attachment \*\*\*\*\* is also considered to be this operation gestalt to the residue of a cell as it is in transition of the pole. For example, the degree of the pole of the transfer function of the discrete time system which carries out a presumed operation is assumed to be a high order thing compared with the degree of the pole in the transfer function of the continuous system of the alternating current equal circuit beforehand appointed to the cell 11. Here, when the degree of the pole of a transfer function is assumed to be the 30th order, a transfer function  $G(z, \theta)$  is expressed with the following formulas.

[0092]

[Equation 17]

$$G(z, \theta) = \frac{b_1 z^{-1} + b_2 z^{-2} + \dots + b_{30} z^{-30}}{1 + a_1 z^{-1} + a_2 z^{-2} + \dots + a_{30} z^{-30}} \quad \dots (34)$$

[0093] It asks for 30 poles of the transfer function  $G(z, \theta)$  obtained by the operation using a discharge method algorithm after convergence of the multiplier parameter  $\theta$ . Drawing 14 is a graph which shows the example of the location in  $z$  flat surface of the 30th pole. As shown in drawing 14, the condition of a cell 11 is analyzed by extracting all the poles relevant to a cell 11 and an impedance component 12, and analyzing transition of the specific pole in it. The judgment of a residue can be performed by observing the pole pinpointed when there were a residue and correlation by experiment etc. beforehand.

[0094]

[Effect of the Invention] Since the condition of a cell is analyzed using the correlation between the pole and conditions, such as a residue of a cell, in the transfer function of the alternating current equal circuit of a cell according to this invention as mentioned above after asking for the transfer function of the discrete time system of the system which contains a cell first by the presumed operation and asking for the pole in the transfer function of the continuous system of the alternating current equal circuit of a cell

from the transfer function of this discrete time system, the condition of a cell can be performed certainly and quantitatively.

[0095] Moreover, in order to carry out the presumed operation of the transfer function of a discrete time system, analog signal processing is unnecessary, since digital signal processing can perform all, LSI-ization by the one chip microcomputer, DSP, etc. is attained, and low cost and the condition analysis equipment of a highly precise cell can be realized.

[Brief Description of the Drawings]

[Drawing 1] The circuit diagram in which being drawing for explaining the principle of this invention, and showing the alternating current equal circuit of a cell

[Drawing 2] The circuit diagram in which being drawing for explaining the principle of this invention, and showing the alternating current equal circuit of a cell when the frequency of an AC signal is comparatively high

[Drawing 3] The graph which is drawing for explaining the principle of this invention, and shows the complex impedance plot of a cell

[Drawing 4] Drawing showing the ARX (autoregression) model which is drawing for explaining the principle of this invention, and is used for system identification

[Drawing 5] Drawing which is drawing for explaining the principle of this invention, and expresses the map to s flat surface for changing into the pole in the transfer function of a continuous system the pole for which it asked from the transfer function of the discrete time system of a cell from z flat surface

[Drawing 6] Drawing in which being drawing for explaining the principle of this invention, and showing change of the complex impedance plot accompanying change of the residue of a cell

(a) Drawing showing the case of 100% of residues

(b) Drawing showing the case of 50% of residues

(c) Drawing showing the case of 10% of residues

(d) Drawing which divided, respectively in the case of 0% of residues, and was shown

[Drawing 7] Drawing in which being drawing for explaining the principle of this invention, and showing correlation with the residue of a cell, and the angular frequency of the pole in the transfer function of a cell

(a) Drawing showing the case of the 1st pole

(b) The graph which divided, respectively in the case of the 2nd pole, and was shown

[Drawing 8] Drawing showing the configuration of the condition analysis equipment of the cell concerning 1 operation gestalt of this invention

(a) is drawing showing the system which impresses an AC signal on a cell.

(b) is the block diagram showing the configuration of the part which performs condition analysis of a cell.

[Drawing 9] The flow chart which shows actuation of the condition analysis equipment of the cell concerning 1 operation gestalt of this invention shown in drawing 8

[Drawing 10] The graph which shows an example of the frequency characteristics of the pseudo-random noise generating means used in 1 operation gestalt of this invention

[Drawing 11] Drawing which is used as a pseudo-random noise generating means in 1 operation gestalt of this invention and in which showing the configuration of the noise source using an M sequence sign

[Drawing 12] The block diagram showing the configuration of the pole calculation means in the condition analysis equipment of the cell concerning 1 operation gestalt of this invention

[Drawing 13] Drawing in which being condition analysis equipment of the cell concerning 1 operation gestalt of this invention, being drawing showing a configuration although an AC signal is impressed to a cell, without minding an impedance component, and showing only the system which impresses an AC signal to a cell.

[Drawing 14] The graph which shows the example of the location of the pole in z flat surface in case the degree of the pole in the transfer function of a cell is the 30th order

[Description of Notations]

VB Alternating voltage concerning a cell

iB Alternating current which flows on a cell

11 Cell

12 Pseudo-random Noise Generating Means

12A Electrical-potential-difference offset pseudo-random noise generating means

13 Impedance Component

14 Analog-to-digital Converter (Sampling Means)

15 Transfer Function Operation Means

16 Pole Calculation Means

16a Factorization operation means

16b Pole operation means

16c Pole conversion operation means

16d Pole temperature compensation means

17 Condition Judging Means

18 Temperature Sensor (Thermometry Means)

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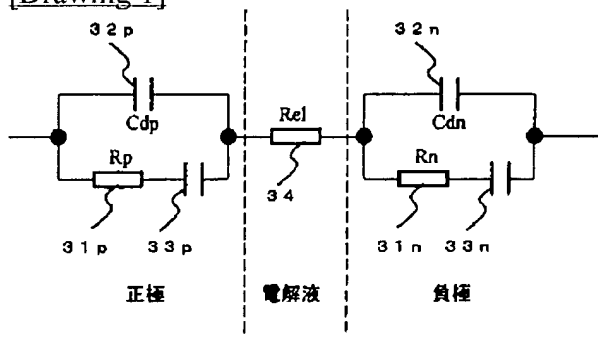
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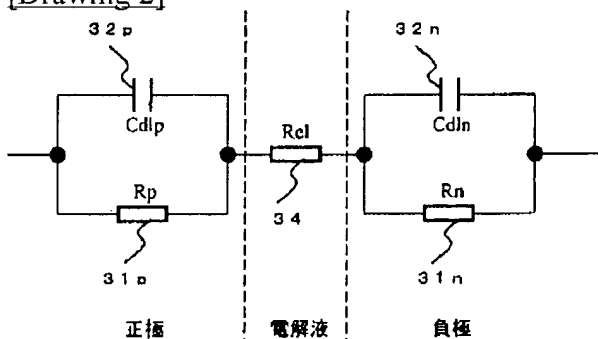
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2. \*\*\*\* shows the word which can not be translated.
3. In the drawings, any words are not translated.

## DRAWINGS

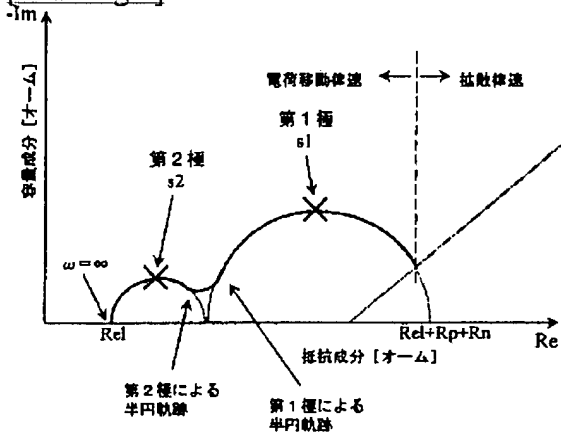
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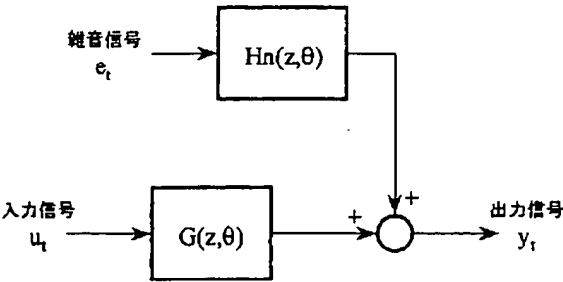
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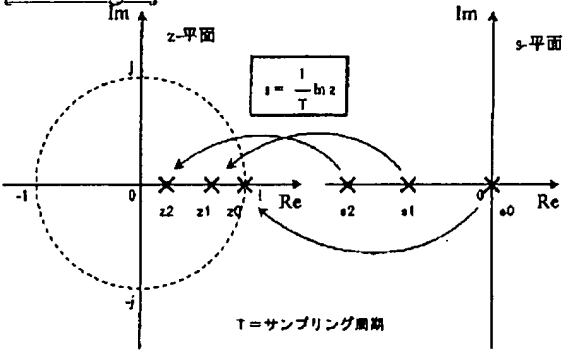
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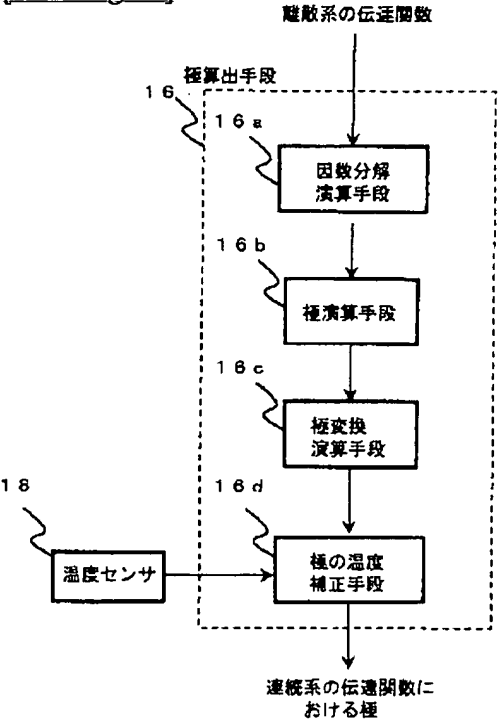
[Drawing 4]



[Drawing 5]

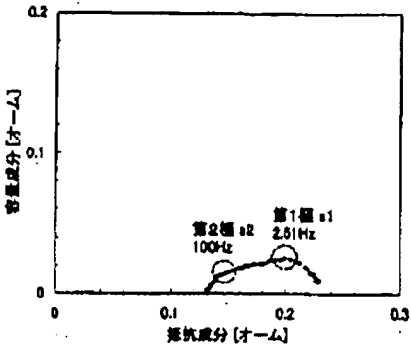


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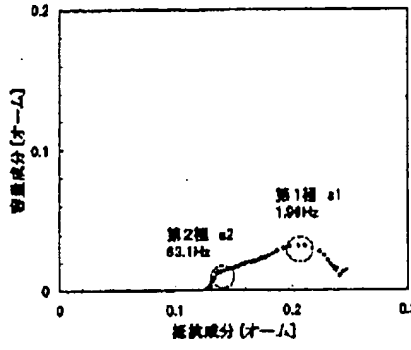


[Drawing 6]

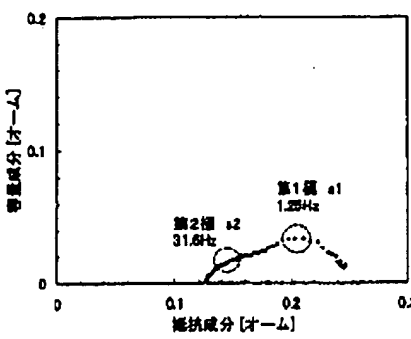
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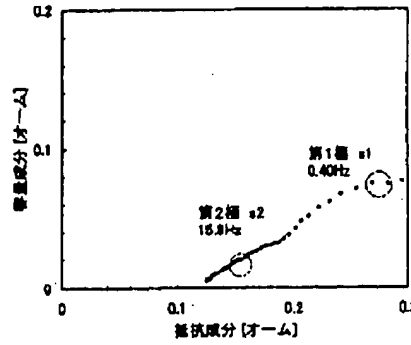
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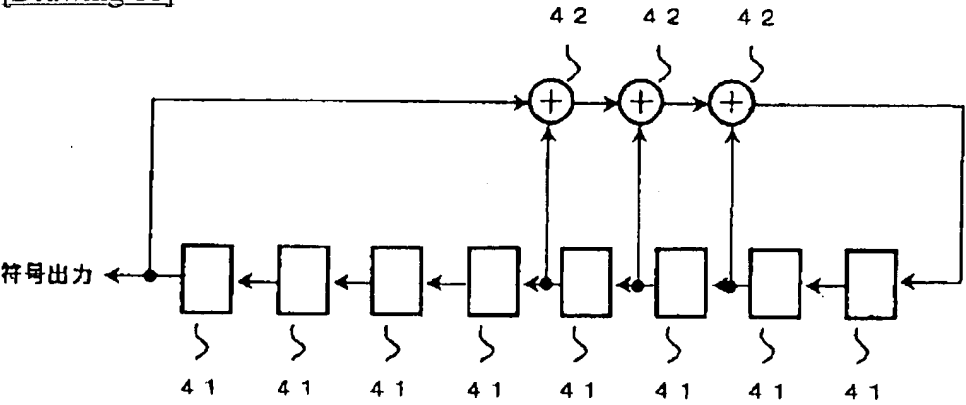
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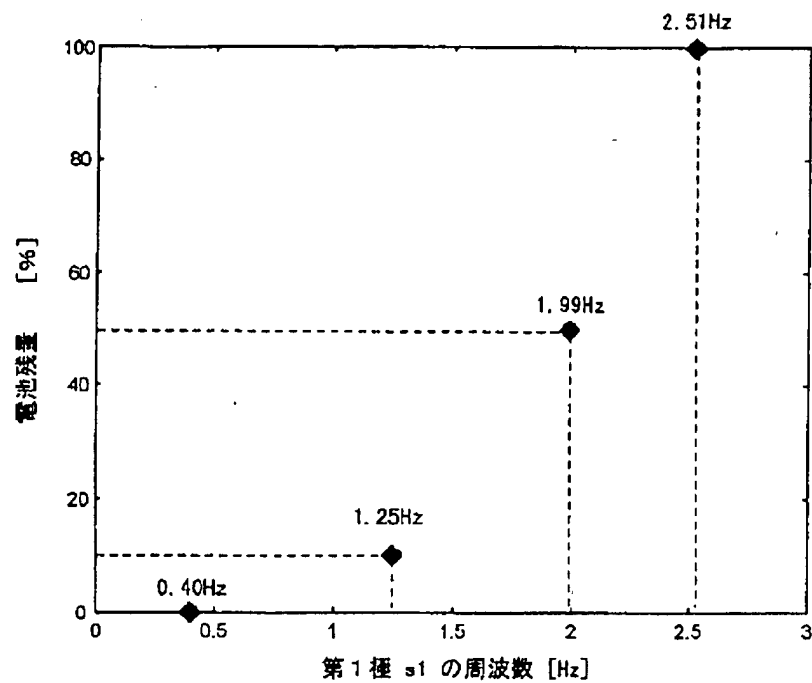


[Drawing 11]

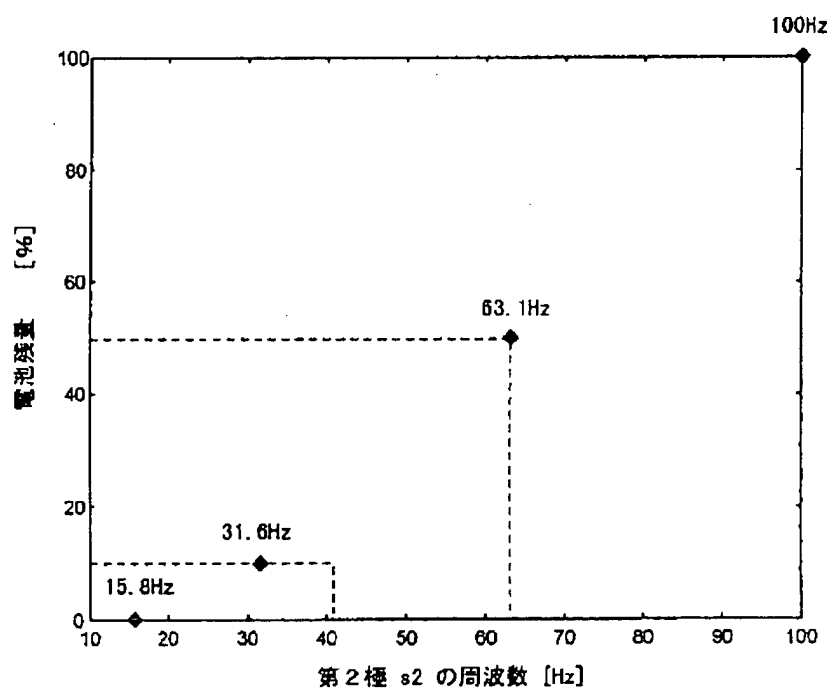


[Drawing 7]

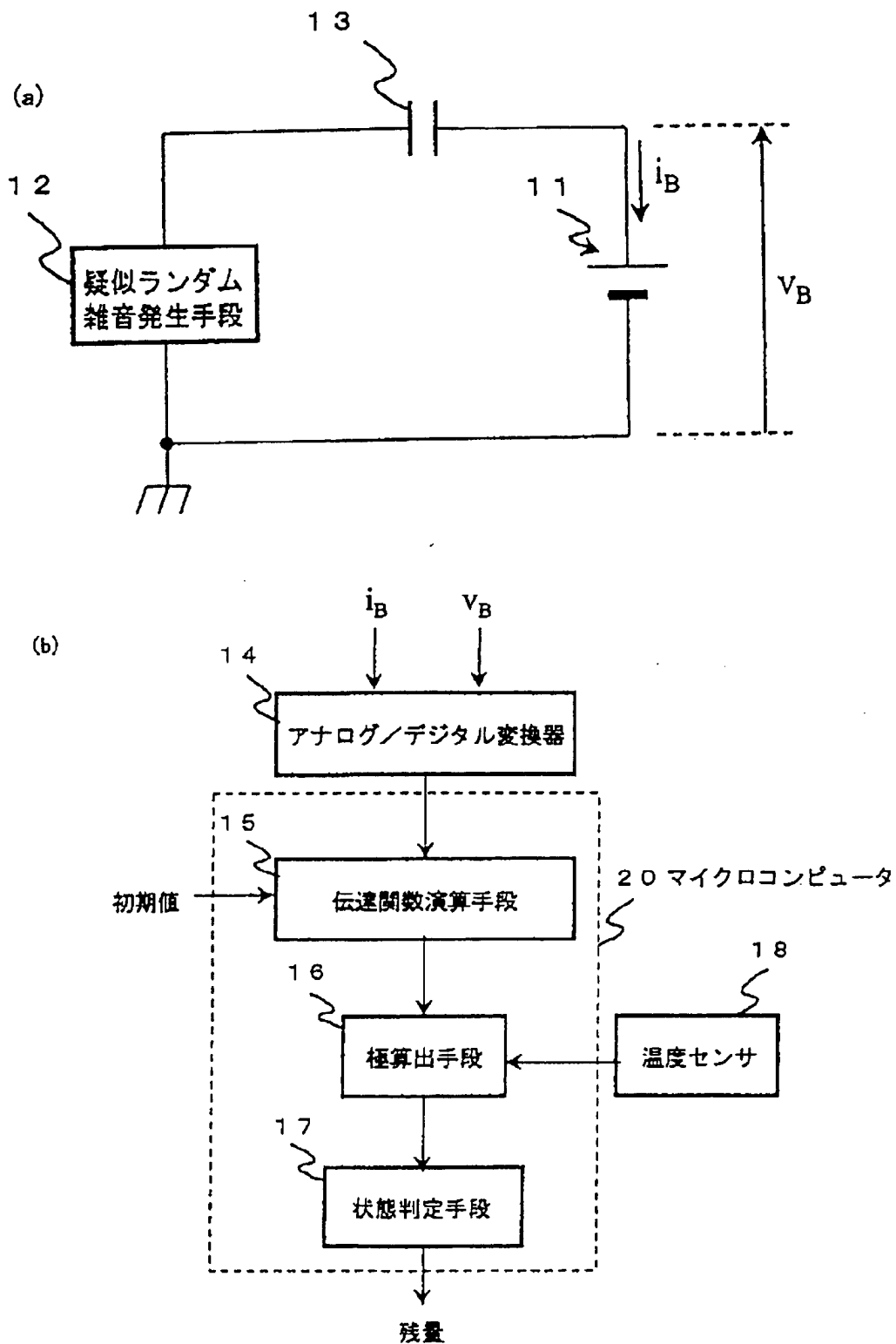
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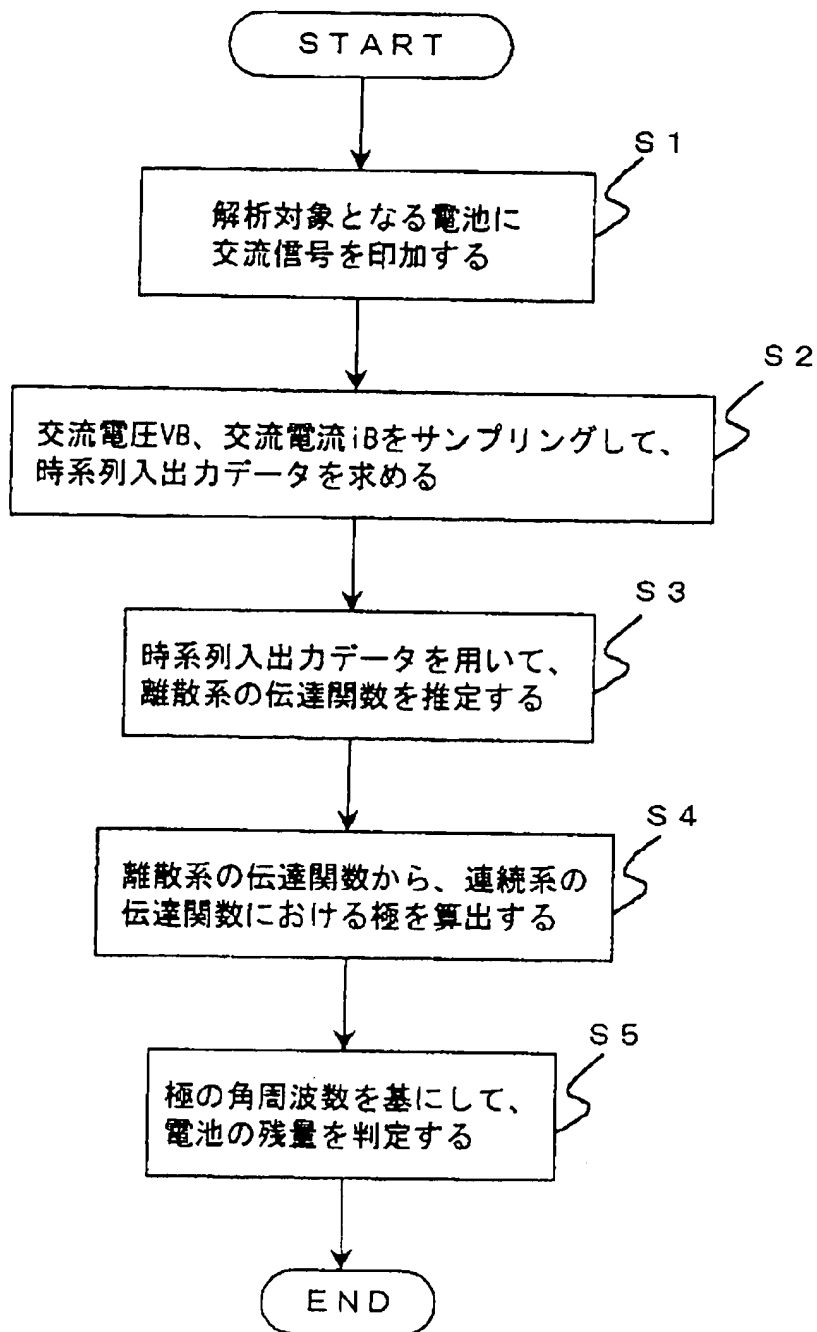
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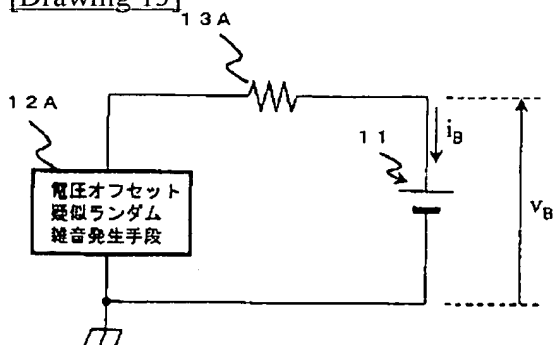
[Drawing 8]



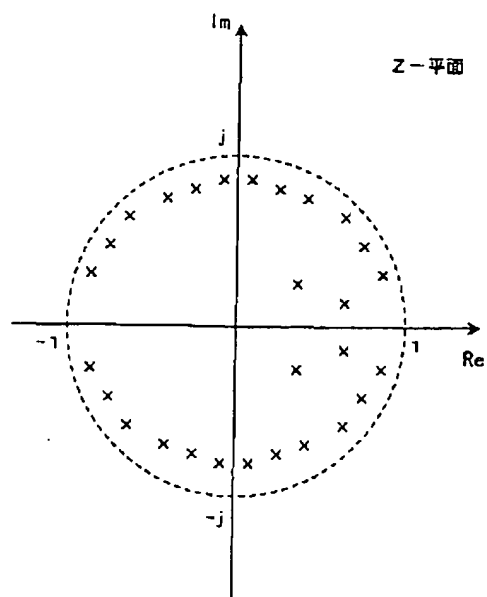
[Drawing 9]



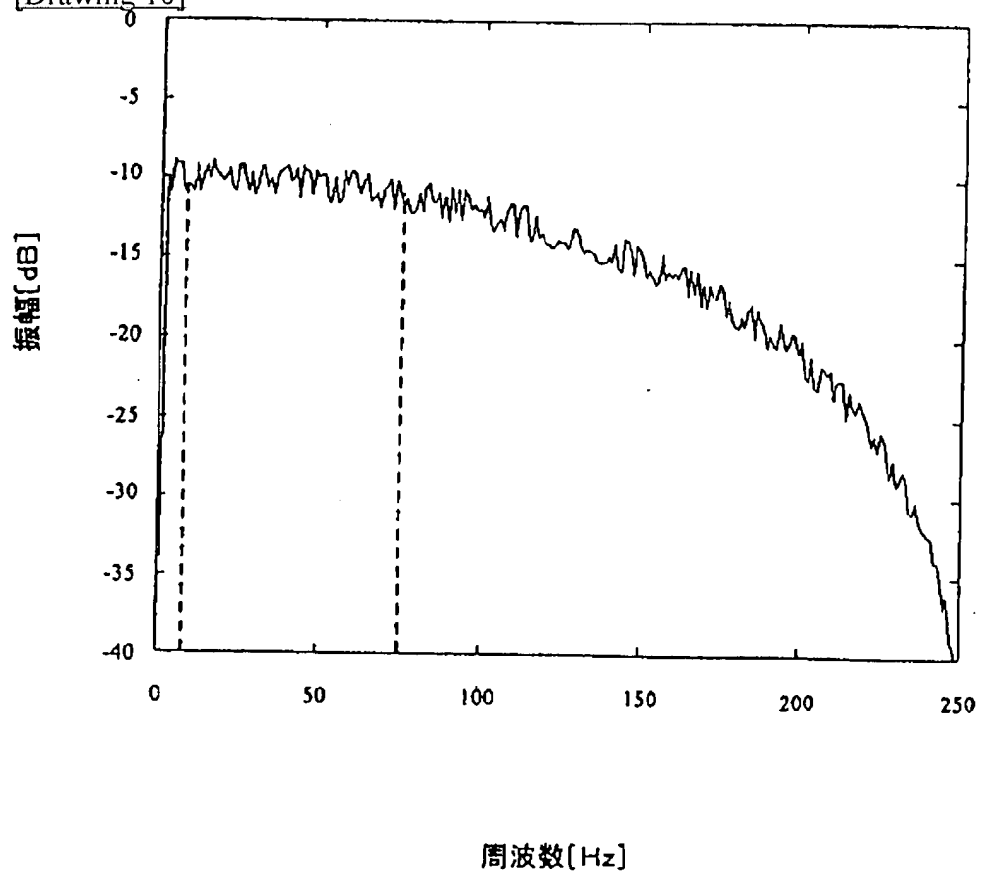
[Drawing 13]



[Drawing 14]



[Drawing 10]



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